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Calcium Carbonate Effects on Soil Textural Class in Semiarid Wildland Soils

RICHARD E. FRANCIS
RICHARD AGUILAR

USDA Forest Service
Rocky Mountain Forest and Range Experiment Station
Albuquerque, New Mexico, USA

Soils from the upper Rio Puerco watershed and El Malpais wilderness study area in New Mexico were analyzed for particle-size distribution and classified into 1 of 12 textural classes before and after calcium carbonate ($CaCO_3$) removal. The samples selected for analysis had a $CaCO_3$ content of ≥5% by volume that represented 32% of the total study samples. All of the samples having $CaCO_3$ changed particle-size distribution, and 60% of those samples changed textural class following the pretreatment for $CaCO_3$ removal. The greatest changes in particle size were from sand- to clay-size fractions. Therefore, we recommend that all wildland soil samples from the semiarid Southwest be pretreated for $CaCO_3$ removal prior to particle-size analysis and subsequent textural classification.

Keywords particle size, soil analysis, textural classification, semiarid soils, Rio Puerco, El Malpais, New Mexico

Soil textural classification is an important element needed to convey the physical properties of a soil in relation to chemical reaction, plant community structure, ecological potential, and resource management. Also, soil water infiltration, retention, and movement through the profile are highly affected by soil texture. Three particle-size fractions used to determine textural class are sand, silt, and clay. These 3 particle-size fractions are used to arrive at 14 specific soil textural classes determined by the relative proportions (percent) of each fraction in a soil sample (Soil Survey Staff, 1975).

Inorganic carbonate may accumulate in soils through pedogenic processes or may be inherited from calcareous parent materials. Due to hot, dry conditions during most of the year, desert soils are generally low in organic matter and highly mineralized. These conditions may result in saline or alkaline soils and the formation of secondary calcium carbonate ($CaCO_3$) (McGinnies, 1981). Subsequently, due to wind transport of particulate matter from source areas, secondary $CaCO_3$ generally accumulates within the profile of many soils in these regions (Fairbridge & Finkl, 1979). The zone of carbonate accumu-

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Address correspondence to Richard Aguilar, Geohydrology Dept., P.O. Box 5800, MS-1324, Albuquerque, NM 87185-1324, USA.

lation occurs at variable depths, reflecting the average, long-term maximum depth of penetration of soil water moisture. Carbonate is commonly precipitated as silt crystals (2–50 μm) in the soil but also occurs in indurated forms as nodules and/or as hard calcareous (travertinous) layers called caliche or calcrete (Fairbridge & Finkl, 1979).

Calcium carbonate bonds to clay and/or silt particles, which affects particle-size analysis (PSA). Highly aggregated, stable clay soils may behave like coarse sands in terms of water infiltration; hence, they may be mistakenly identified in the field as sands or coarse loams. In reality, these same soils, having significant microporosity and high exchange capacities, retain water and nutrients much better than sands (Gee & Bauder, 1986).

An important step in PSA, based upon Stoke's law, is the treatment of samples to enhance separation or dispersion of aggregates (Gee & Bauder, 1986). Soils may contain aggregates, such as secondary $CaCO_3$, that are not readily dispersed and bind particles together. Therefore, chemical pretreatment should be used to remove carbonate coatings and secondary $CaCO_3$ aggregates for accurate particle-size distribution (PSDs) and subsequent textural classification.

The objective of our study was to determine the quantitative effects of $CaCO_3$ on soil PSA and how this relates to soil textural classification of semiarid soils found in north- and west-central New Mexico.

Study Areas and Methods

Our study was conducted on the upper Rio Puerco watershed and the El Malpais wilderness study area in New Mexico (Figure 1). The Rio Puerco watershed is 100 km northwest of Albuquerque and ranges in elevation from 1,662 m to 2,743 m. The climate is semiarid, and the mean annual precipitation ranges from 215 to 323 mm, depending upon elevation (Francis, 1986). The Rio Puerco is mostly intermittent or ephemeral and contributes about

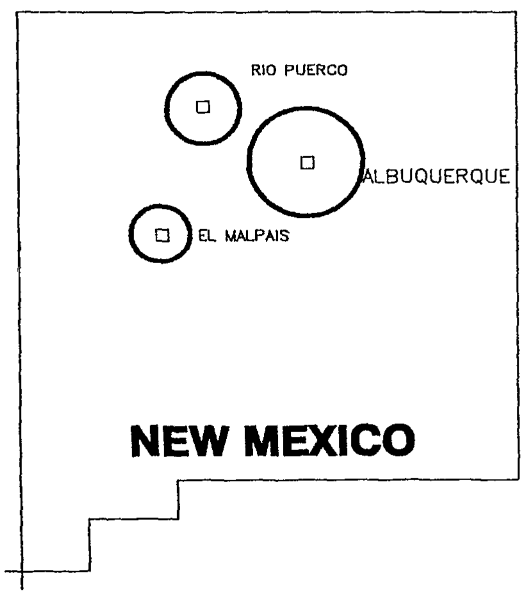

Figure 1. General location of the Rio Puerco and El Malpais study areas in New Mexico.

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Results and Discussio

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45% of the entire sediment load to the Rio Grande (Dortignac, 1963). El Malpais (lava flow badlands) is in west-central New Mexico 160 km west of Albuquerque. Its mean elevation is 2,250 m, and annual precipitation ranges from 227 to 357 mm, depending on elevation. Most of the Rio Puerco and El Malpais soils are Aridisols, Entisols, and Alfisols with a few Inceptisols, Vertisols, and Mollisols; part of the El Malpais is exposed lava flows (basalt) (Francis, 1986; Francis & Williams, 1989; Okoye, 1993).

The upper Rio Puerco watershed has been classified into phytoedaphic communities on the basis of current vegetation and soil mapping units (Francis, 1986). Plant communities on the El Malpais have been classified on the basis of existing vegetation (Francis & Williams, 1989).

To establish soil-vegetation relationships on a site-specific basis, soil pits were excavated and described according to established guidelines (Soil Survey Staff, 1981) along permanent study transect locations within each study area; total transects numbered 256. Representative soil samples were collected from genetic horizons described for each soil profile characterized for a total of 1,436 samples from both study areas.

The soil samples were analyzed for several physical and chemical properties, including percentage $CaCO_3$ content and PSD. PSA was carried out with and without $CaCO_3$ removal to determine the effects on resulting PSD and subsequent textural classification of the samples. The $CaCO_3$ was removed with 1 *M* NaOAc, and the final PSA was determined using the pipette method (Gee & Bauder, 1986); initial PSA (before $CaCO_3$ removal) used the standard hydrometer method (Day, 1965).

The $CaCO_3$ equivalent of the soils was determined by the acid neutralization method (Richards, 1969). Selection of samples for pretreatment (removal of $CaCO_3$) prior to PSA was set at the ≥5% $CaCO_3$ equivalent based on the taxonomic definition of a calcic horizon (Soil Survey Staff, 1975). Paired t-tests were used to determine the statistical significance of pretreatment and posttreatment differences, and Kappa (K) analysis (Agresti, 1990) was used to determine the disagreement of pretreatment and posttreatment categories for PSD and texture. The standard procedure for PSA is pretreatment of all samples for calcium removal. However, results of a survey we conducted revealed that this procedure is not routinely carried out by analytical soil testing laboratories at land-grant universities (Table 1). The procedure is done only by request because the majority of the analyses deal with agricultural soils that are low (<5%) in $CaCO_3$.

Results and Discussion

Of the 1,436 soil horizon samples taken, 32% ($n = 459$) had a $CaCO_3$ equivalent of ≥5%. Following an initial hydrometer PSA analysis without $CaCO_3$ removal, the samples were pretreated ($CaCO_3$ removal) and reanalyzed for PSD by the pipette method. The PSD of all 459 treated samples changed, and 60% of these ($n = 277$) changed textural class.

Sand was the dominant particle-size fraction of all samples prior to $CaCO_3$ removal (Figure 2). The greatest changes upon $CaCO_3$ removal were in the sand and clay fractions. Clay content increased significantly ($p = 0.05$) in 56% of the treated samples, the sand fraction decreased significantly ($p = 0.05$), and the silt fraction decreased minimally.

The most prevalent textural class prior to $CaCO_3$ removal was sandy loam (51%). As a result of $CaCO_3$ removal and PSD changes, 60% of the treated samples ($n = 277$) changed textural class from sandy loam (52% decrease) and loam (30% decrease) to sandy clay loam (27% increase), clay loam (30% increase), and clay (17% increase) (Figure 3). As a result of textural class changes, 75% ($K = 0.25$) of the treated samples disagreed with their pretreatment textural class (Table 2).

Table 1
Survey of 11 soil testing laboratories at western land-grant universities (Fall, 1993)

Laboratory	Routine $CaCO_3$ Pretreatment done	Instrument	Cost per sample ($U.S.)
Univ. of California	No, must request	hydrometer	9.00
Colorado State	No, must request	hydrometer	7.50
Univ. of Arizona	No, must request	hydrometer	8.50
New Mexico State	No, must request	hydrometer	10.00
Oklahoma State	No, must request	hydrometer	7.00
Kansas State	No, must request	hydrometer	5.00
Univ. of Nebraska	No, must request	hydrometer	11.00
Texas A&M	No, must request	hydrometer	10.00
Utah State	No, must request	hydrometer	12.00
Washington State	No, must request	hydrometer	closed 1980
Univ. of Idaho	No, must request	hydrometer	9.00

An example of the effects of $CaCO_3$ on soil textural classification within one pedon (sample site) is shown in Figure 4. This soil was initially classified in the field as a fine Ustollic Camborthid and reclassified as a coarse loamy Ustollic Haplargid using field characterization data and laboratory data including the PSA without pretreatment for $CaCO_3$ removal. Field tests for $CaCO_3$ content (effervescence reaction to 1 *M* HCl) showed the A and Bky1 horizons strongly effervescent, while the 2Bky2 and 2Bky3

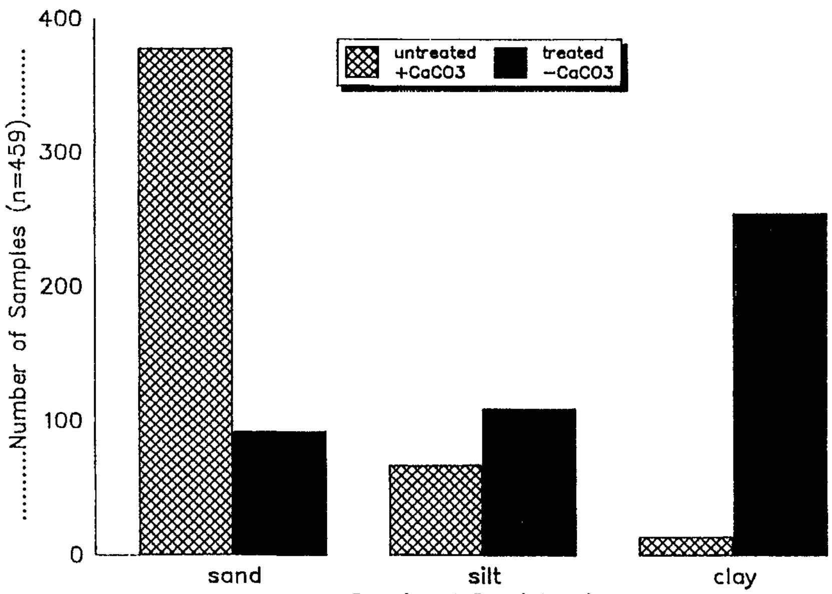

Figure 2. Dominant particle-size fractions of all treated and untreated soil samples with ≥5% $CaCO_3$ (n = 459). The number of sand-dominated samples decreased and the number of clay-dominated samples increased with $CaCO_3$ removal.

'and-grant universities (Fall, 1993)

Instrument	Cost per sample ($U.S.)
hydrometer	9.00
hydrometer	7.50
hydrometer	8.50
hydrometer	10.00
hydrometer	7.00
hydrometer	5.00
hydrometer	11.00
hydrometer	10.00
hydrometer	12.00
hydrometer	closed 1980
hydrometer	9.00

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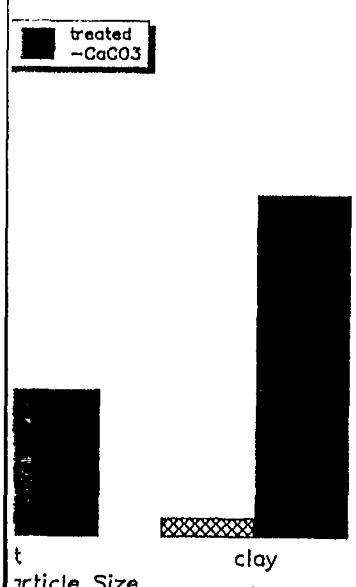

·d and untreated soil samples with ≥5% ıples decreased and the number of clay-

Table 2

Number of textural classes in agreement between pretreatment and posttreatment

Post-treatment (without $CaCO_3$)	Pretreatment (with $CaCO_3$)											
	S	SC	SCL	SL	Si	SiL	SiC	SiCL	L	LS	CL	C
S	1 (0.002)											
SC				1								
SCL			24 (0 05)	64					7*	1*	4*	
SL			3	89 (0 19)					6*	3*	1*	
Si												1*
SiL				2							1*	1*
SiC				4		2			2		1*	
SiCL						6			8		1*	
L				22		2			50 (0.11)	1		1*
LS				1						2 (0.004)		
CL			5	26		2			50		9 (0 02)	1
C			3	25					12	1	6	7 (0.02)

Numbers in parentheses are the proportion of the total samples (n = 459) in this category; pooled Kappa = 0.25, or 25% agreement/75% disagreement. Diagonal represents unchanged classes S, sand; C, clay; L, loam; Si, silt.

*Classes are meaningless probably due to procedural error.

horizons were violently effervescent. The mean $CaCO_3$ content for the entire profile was 30%. The carbonates were disseminated in the A horizon, and present as common fine seams in the Bky1 and as many fine seams in the 2Bky2 and 2Bky3. Throughout the soil profile, the most marked particle-size fraction change following $CaCO_3$ removal was a mean 37% increase in clay and a 38% decrease in sand fractions. The horizon textures (A, Bky1, 2Bky2, 2Bky3) changed from sandy loam to silty clay loam or clay, demonstrating the strong influence of $CaCO_3$ on PSA. The family particle-size classification for the soil changed from coarse loamy to clayey as the percentage of weighted average clay increased from 7% to 48% in the control section (25- to 100-cm depth) with $CaCO_3$ removal.

Another striking example of the effects of $CaCO_3$ on soil texture determination within a soil profile is shown in Figure 5. This soil was classified as a clayey, fine Aridic Haplustalf and reclassified as a clayey, fine Torrertic Argiustoll using the field and lab characterization data. The soil had the most prevalent PSA change in the silt fraction following $CaCO_3$ removal. Silt content increased in all five horizons upon $CaCO_3$ removal, with a corresponding change in textural class in three of these. The silt fraction of the A, BA, and Bky horizons increased by 24%, 48%, and 47%, respectively. The Bt and Btky horizons increased in silt content by 9% and 6%, respectively. Sand decreased in all horizons, while clay increased in the Bt horizons and decreased in the others. The A, BA, and Bky horizons changed textural class from clay loam or clay to silty loam or silt. The mean $CaCO_3$ content of the pedon was 7%, with an overall slight increase with depth from 6.9% to 8.0%. In this case, the family particle-size class did not change after $CaCO_3$ removal because the clay fraction in the soil's control section (upper 50 cm of the argillic horizon; Bt and Btky) only increased an average of 4% upon removal of $CaCO_3$. However, the increase in the silt fraction and the corresponding decrease of sand and clay in the A, BA, and Bky horizons demonstrate that $CaCO_3$ has a strong influence on the overall PSD of a soil profile, but might not result in a change in family particle-size classification. Yet these differences in PSD and subsequent classification of soil texture would play an

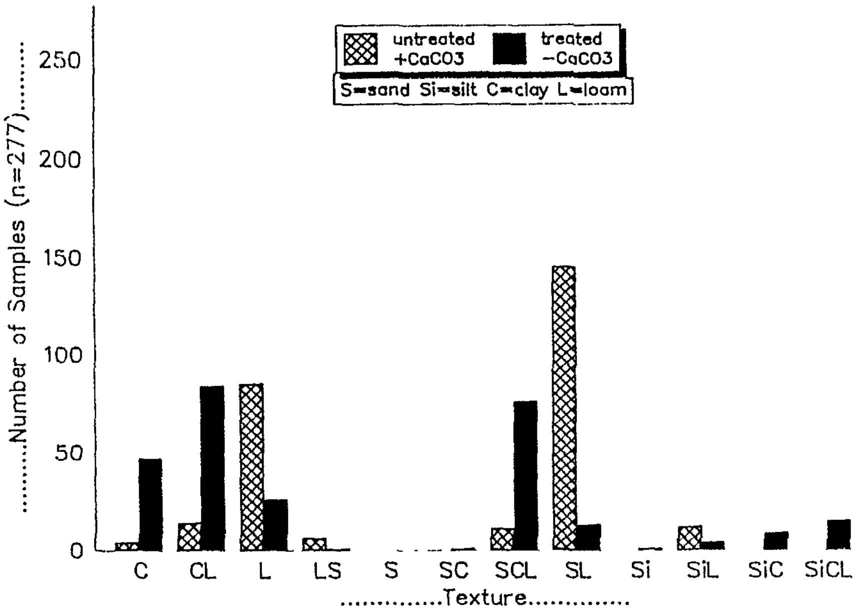

Figure 3. Soil textural class of those soil samples with ≥5% $CaCO_3$ (n = 277) that changed classification.

important role in the interpretation of many important field attributes, such as plant water availability, soil water infiltration, surface runoff, and erosion potential.

For all soil profile samples analyzed, the mean $CaCO_3$ content for those samples with ≥5% $CaCO_3$ (n = 459) was 12.6%. However, the mean was significantly (p = 0.05) greater for the Rio Puerco sites (12.7%) than for the El Malpais sites (1.6%)—a reflection of the $CaCO_3$ content in the original soil parent material, which was calcareous sedimentary rock in the Rio Puerco study area and weathered basalt in El Malpais. The sample with the greatest $CaCO_3$ content from the El Malpais study area contained 35.0% $CaCO_3$, compared with 49.4% $CaCO_3$ for the sample from the Rio Puerco area. The El Malpais sample textural classification changed from loam to clay, while the Rio Puerco sample remained a sandy loam following $CaCO_3$ removal.

The greatest mean $CaCO_3$ content by genetic horizon was 12.3% for the 2Bkyl horizons sampled from the Rio Puerco study area (Table 3). These horizons had a mean thickness of 35.8 cm. The Bk horizons had a mean $CaCO_3$ content of 9.8% and a mean thickness of 40 cm, with horizon thickness depending on landscape position, which ranged from valley bottom to mesa top; the majority occurred on ridge slopes. Most of the Bk horizons changed textural class following $CaCO_3$ removal.

Once again, comparing the treated samples from Rio Puerco (n = 455) with those of the El Malpais (n = 4), the mean $CaCO_3$ content was 12.7% and 1.6%, respectively. For those samples that also changed textural class (n = 277), the mean $CaCO_3$ for Rio Puerco

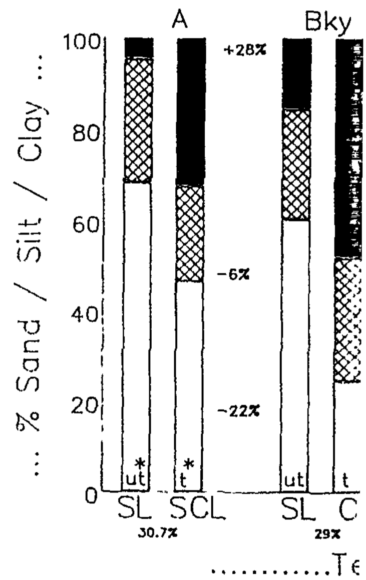

Figure 4. Example of particle-size d
horizon of a soil profile from untreated
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textural classes. The PSD change
corresponding increase in silt and
number of "fine" textural classes

We encountered a circumstan
reflect what was occurring in the
Keys to Soil Taxonomy (Soil Ma
Argid and Ustalf and the great g
(Okoye, 1993). The soil at one of
2Btky2 and 2Btky3 horizons (35-
abundance of $CaCO_3$ was not exp
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classified as a Calciorthid due to
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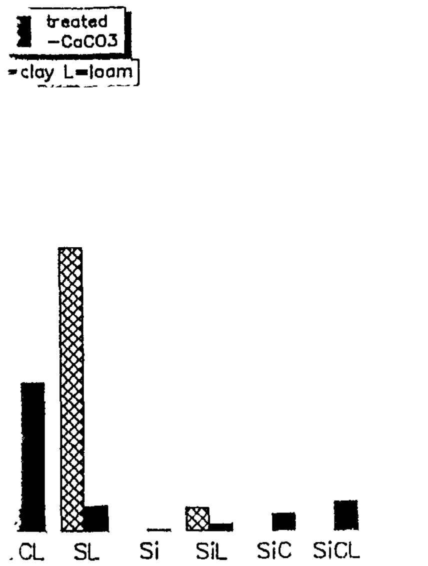

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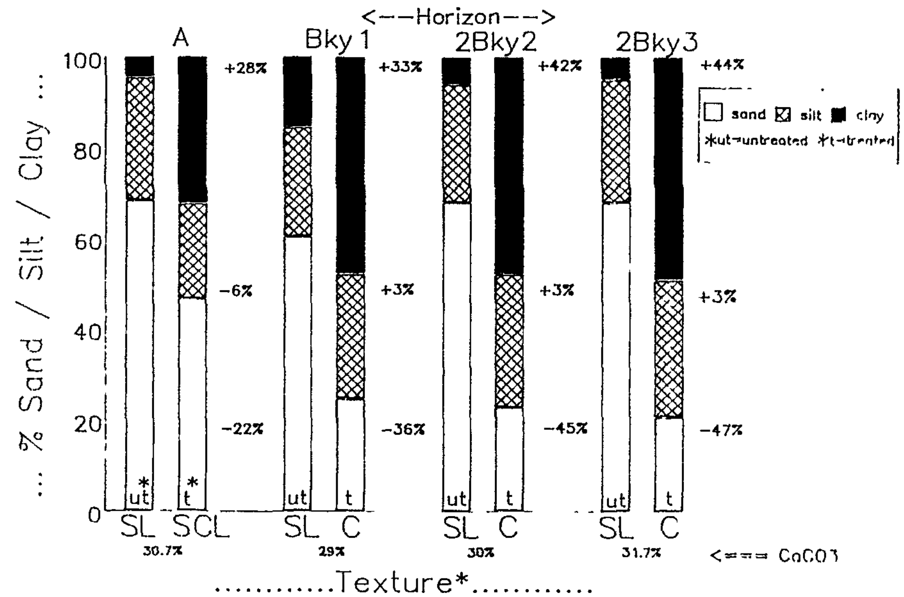

Figure 4. Example of particle-size distribution, textural class change, and $CaCO_3$ content by horizon of a soil profile from untreated and treated samples. The most dramatic change in this pedon was the increase in clay following $CaCO_3$ removal. Numbers to the right of each horizon pair represent the percentage change (±) in each sample after $CaCO_3$ removal. This soil from the Rio Puerco study area was classified as coarse loamy prior to $CaCO_3$ removal and clayey, fine after $CaCO_3$ removal.

textural classes. The PSD change most often affected was a decrease in sand with a corresponding increase in silt and clay (Figure 2). These changes resulted in a greater number of "fine" textural classes (Figure 3).

We encountered a circumstance where standard methods of classification did not reflect what was occurring in the field. The recognition and expression of $CaCO_3$ in *Keys to Soil Taxonomy* (Soil Management Support Services, 1985) for the suborders Argid and Ustalf and the great group Camborthid were ineffective in our study area (Okoye, 1993). The soil at one of our sample sites with a $CaCO_3$ content of ≥30% in the 2Btky2 and 2Btky3 horizons (35- to 94-cm depth) was classified as a Haplargid. The abundance of $CaCO_3$ was not expressed in the taxonomic classification of the soil even at the family level because of the presence of an argillic horizon (Table 4, sample site I119). In contrast, another soil (E62) had only about half as much carbonate and was classified as a Calciorthid due to the absence of an argillic horizon. Small amounts of $CaCO_3$ have an important effect on the physical and chemical properties of soils and, subsequently, their management (Hallmark, 1985). Richardson and Lewis (1985) suggested that carbonate abundance should be expressed before or at the family level to provide information for agricultural, engineering, and/or other applied purposes, including communicating research results among soil scientists and other natural resource scientists and managers.

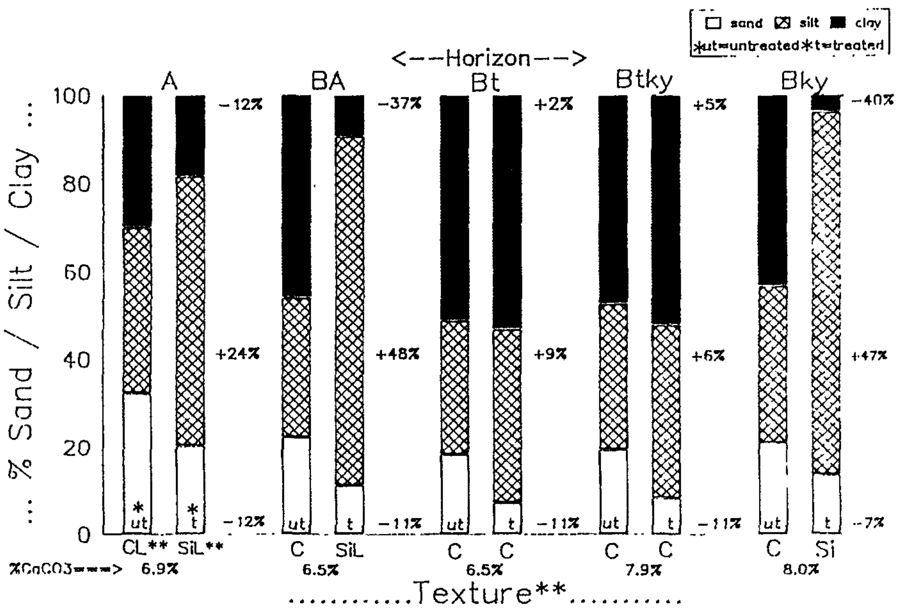

Figure 5. Example of particle-size distribution, textural class change, and $CaCO_3$ content by horizon of untreated and treated samples from a soil pedon. In this example, the silt fraction changed the most after $CaCO_3$ was removed. Numbers to the right of each horizon pair represent the percentage change (±) in particle-size distribution after $CaCO_3$ removal. This soil from the Rio Puerco study area was classified as a clayey, fine Aridic Haplustalf prior to $CaCO_3$ removal and a clayey, fine Torrertic Argiustoll after $CaCO_3$ removal.

Conclusions

Whether or not to remove secondary $CaCO_3$ from samples prior to PSA raises a "rhetorical red flag" because so many Southwestern soils occur naturally with $CaCO_3$ and most soil-plant relationship studies deal with soil in situ. Soil texture is necessary for comprehensively describing soil physical attributes. Are we thus interpreting an "unrealistic" field condition by removing $CaCO_3$ prior to PSA of soils from semiarid Southwest wildlands? $CaCO_3$ affects soil physical properties by the formation of secondary sand- and silt-sized granules that mimic primary particles, which not only affects PSD, but also affects soil structure and pedogenic development by controlling infiltration and aeration rates. All of these factors directly or indirectly affect ecological interpretation, classification, and management decisions. Therefore, the decision to remove $CaCO_3$ before PSA should be determined by the study objective(s). If a study on soils in semiarid wildlands requires PSA, then (1) determine $CaCO_3$ content for all samples in the profile, (2) determine if $CaCO_3$ removal affects PSA, and (3) evaluate to what degree the resulting PSD and soil textural classification affect subsequent standarized soil classification and interpretations on site capability and management prescriptions.

We recommend that all arid wildland soil samples analyzed for PSD be pretreated for $CaCO_3$ removal prior to PSA because the resulting PSD and subsequent textural classification are strongly dependent upon this analysis. As our survey of soil testing laboratories in western land-grant universities revealed, this procedure is not routinely carried

Mean $CaCO_3$ and m...
samples (n = 1,...

Horizon[a]	Number of samples
A	220
A1	51
E	12
BA	4
B2	1
Bk	41
Bk1	75
Bky	33
Bty	5
Btk1	159
Btky1	10
Bt1	155
Bw1	53
By1	42
2BC	1
2Bk1	15
2Bky1	12
2Bt1	11
2Btk1	20
2Bty	2
2Btky1	9
2By1	7
3Bk	3
3Bky	2
3Btk	
4By	4
4Btyb	1
C	38
C1	113
2C1	37
3C1	10

[a]Horizons may include ...
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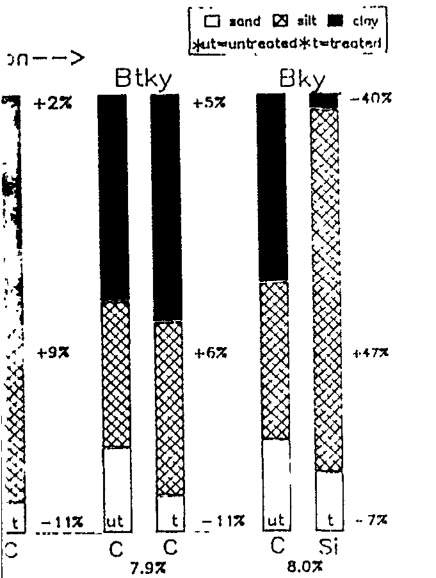

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...al class change, and $CaCO_3$ content by ...on. In this example, the silt fraction changed ... right of each horizon pair represent the ...r $CaCO_3$ removal. This soil from the Rio ...c Haplustalf prior to $CaCO_3$ removal and a

...n samples prior to PSA raises a "rhe- ...soils occur naturally with $CaCO_3$ and ...il in situ. Soil texture is necessary for ...es. Are we thus interpreting an "unre- ...o PSA of soils from semiarid Southwest ...by the formation of secondary sand- and ... which not only affects PSD, but also ...by controlling infiltration and aeration ...ect ecological interpretation, classifi- ...ecision to remove $CaCO_3$ before PSA ...a study on soils in semiarid wildlands ...for all samples in the profile, (2) deter- ...luate to what degree the resulting PSD ...andarized soil classification and inter- ...scriptions.

...ples analyzed for PSD be pretreated for ... PSD and subsequent textural classi- ... As our survey of soil testing labora- ...this procedure is not routinely carried out for standard PSA testing. Therefore, researchers and natural resource managers requesting soil textural analyses should specify $CaCO_3$ removal prior to PSA. If $CaCO_3$ is not removed, soil classification may be compromised. This procedure is extremely pertinent because management decisions for Southwestern wildlands are increasingly being based on standardized classifications of soil/plant communities.

Table 3

Mean $CaCO_3$ and mean depth by genetic horizon and pooled subdivision for all samples (n = 1,436) from the Rio Puerco and El Malpais study areas

	Rio Puerco			El Malpais		
Horizon[a]	Number of samples	Mean thickness (cm)	Mean $CaCO_3$ (%)	Number of samples	Mean thickness (cm)	Mean $CaCO_3$ (%)
A	220	6.4	4.4	26	7.3	0.7
A1	51	17.7	1.6			
E	12	8.6				
BA	4	11.3		11	14.4	0.1
B2	1	20.0				
Bk	41	40.0	9.8	4	28.8	1.6
Bk1	75	37.0	8.6			
Bky	33	38.0	5.7			
Bty	5	23.8	3.0			
Btk1	159	32.4	6.0	14	27.4	5.5
Btky1	10	31.0	4.9			
Bt1	155	13.5	2.7	40	23.6	0.3
Bw1	53	25.7	4.0	6	18.5	0.2
By1	42	35.0	6.8			
2BC	1	>7.0				
2Bk1	15	29.3	6.1			
2Bky1	12	35.8	12.3			
2Bt1	11	18.4	1.4	2	8.5	0.4
2Btk1	20	33.9	9.1	2	28.0	1.2
2Bty	2	27.0				
2Btky1	9	34.7	5.0			
2By1	7	34.1	3.2			
3Bk	3	30.3	5.4	1	25.0	0.8
3Bky	2	48.5	2.6			
3Btk				1	23.0	0.9
4By	4	35.8	1.1			
4Btyb	1	20.0	1.1			
C	38	29.4	7.9			
C1	113	33.0	4.4	15	37.0	2.3
2C1	37	27.6	4.3			
3C1	10	29.2	2.9			

[a]Horizons may include one or all of the following subdivisions and/or layers: 1, 2, 3, 4, 5, b, t, k, y. For example, Bk1 includes Bk1, 2, 3, 4, t.

Table 4
Carbonate expression in soil taxonomy

Sample site number	Horizon	Depth (cm)	$CaCO_3$ (%)	Classification
E62	A	0–5	1 8	Coarse-loamy, mixed, mesic, Ustochreptic Calciorthid
	Bt	5–28	13 5	
	2Btk	28–68	15 0	
	2C	68–96	14 0	
	2Cr	96–120	17 2	
I119[a]	A	0–5	30 7	Coarse-loamy, mixed, mesic, Ustollic Haplargid
	Btky1	5–35	29 0	
	2Btky2	35–68	30 0	
	2Btky3	68–94	31 7	
I122[a]	A	0–5	< 1	Fine-loamy, mixed, mesic, Ustollic Haplargid
	Bt	5–17	6 1	
	2Btky1	17–34	5 6	
	Btky2	34–73	5 8	
	Bky1	73–107	9 8	
	Bky2	105–150+	8 2	

Table modified from Okoye (1993) Horizons are defined in Table 3
[a]Sites are in the same soil mapping unit, but different plant communities (Francis, 1986)

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